UNIT - V

7 HOLOGRAPHY

Introduction

Photography is the method of obtaining images of objects. In photographic method a lens focuses the light reflected from a three dimensional object onto a photographic film where a two dimensional image of the object is formed. Holography is a new technique of obtaining images of objects. The word holography is coined from two Greek words holos and grafe. Holos meaning whole and grafe meaning writing or drawing. Thus holography means drawing the whole (complete) image.

Holography was invented in 1947 by the Hungarian - British physicist Dennis Gabor. For this Gabor was awarded Nobel prize in physics in 1971.

What is holography

Holography is the method of construction of hologram and reconstruction of images from hologram.

Hologram

Hologram is the recording of interference pattern formed between two beams of coherent light coming from the same source. In this process both amplitude and phase components of light wave are recorded on a light sensitive medium such as a photographic plate. In the case of ordinary photography only amplitude of the light wave reflected from the object (to be photographed) is recorded on a photographic plate. What is actually recorded is the light intensity since it is proportional to square of the amplitude. Since the variation in the phase distribution is not recorded the three dimensional character of the object is lost in the photograph. Holography is a method which records both amplitude and phase of the light wave using interferometric techniques. Because of this the image produced by the technique of holography has a true three dimensional form. This doesn't mean that holography is a 3D photography. Though holography is often referred to as 3D photography, this is a misconception. The image reconstructed from a hologram has a true three dimensional form. This means that by looking at the image one can change one's position and view a different perspective of the image similar to viewing the object.

Holography requires an intense coherent light source such as Laser. This is the

reason why holographic technique became practicable only after the invention of lasers.

The first practical holograms that recorded 3D objects were made in 1962 by Yuri Denisyuk in the Soviet Union and by Enmett Leith and Juris Upatnieks at University of Michigan, USA.

Principle of holography

The technique of holography involves two stage processes. First one is the recording of hologram and the second is the reconstruction of image from the hologram. In holography some of the light scattered from an object falls on a recording medium. A second light beam known as the reference beam also illuminates the medium, so that interference occurs between the two beams. The resulting light field generates random pattern of varying intensity which is recorded in the medium gives rise to hologram. When the hologram is illuminated by the original reference beam the reference beam is diffracted by the hologram to produce a diffracted light field which is identical to the light field which was scattered by the object. Thus someone looking into the hologram sees the object even though they are no longer present.

In Gabors original experiments the reference beam and the beam scattered from the object were coaxial. Further advancement was made by Leith and Upatnieks who used the reference beam at an offset angle. That made possible the recording of holograms of 3D objects.

Recording of hologram

To construct a hologram take a broad laser beam (plane wave). It is split into two by a splitter. The two beams are called reference beam and object beam. The reference beam is allowed to fall on a mirror which gets reflected to fall on the photographic plate. The second beam of light is allowed to fall on the object which is to be photographed. This beam of light gets scattered from the object and falls on the photographic plate. This acts as

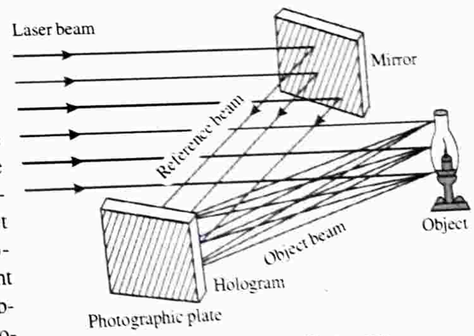

Figure 7.1 : Construction of hologram

a source of spherical wave. At the photographic plate the two beams (reference beam which is a plane wave and object beam which is a spherical wave) get superimposed to form interference pattern. These interference fringes are series of zone plate like rings. These rings are also superimposed making a complex pattern of lines and swirls. The developed negative of the interference pattern is a hologram. The hologram is not the image of the object but carries a record of both intensity and phase of the light wave reflected from each point of the object.

Reconstruction of the image

The hologram does not give us the image of the object directly but it contains it. For reconstruction of image from a hologram, it is illuminated by a parallel beam of light from a laser (preferably original reference beam). Most of the light passes through the hologram. Since the fringes in the hologram act as a diffraction grating, part of the light beam is diffracted. These diffracted rays form two images, a virtual image and a real image. The virtual image is formed at the same location formerly occupied by the object when it was photographed. The real image is formed infront of the hologram. The virtual image is for viewing and the other one is to be photographed. By viewing the virtual image one can feel the 3D effect. i.e. we can perceive the image as if we are looking at the real object. Since the image is seen by looking through the hologram it is called as a transmission hologram.

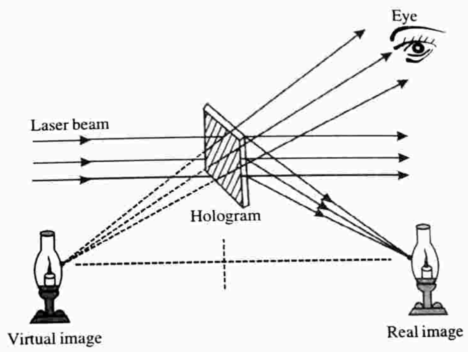

Figure 7.2 : Reconstruction of image from hologram

Advantages of hologram

1. Unlike in ordinary photography hologram can give a 3D effect.
2. In ordinary photography there is only one to one correspondence between the object and the image. In a hologram there is one to many correspondence between the object and the hologram. i.e. Every object point goes to entire hologram. It is due to this fact a very small bit of hologram can reconstruct the entire original object.
3. The information storing capacity of a hologram is very high compared to photography. For example while a 6 × 9 mm photograph can hold one printed page, a hologram of the same size can hold up to 300 printed pages.

Theory

Hologram involves recording of two superposed light beams. One is called reference beam which is a plane wave the other one is a spherical wave called object beam which is reflected from the object to be photographed.

Consider a plane reference wave propagating in the x-z plane inclined at an angle θ with the z-direction. The field associated with this wave is given by

$$r(x, y, z) = A\ \cos(\bar{k}\cdot\bar{r} - \omega t) \qquad \text{......(1)}$$

where $\bar{k}\cdot\bar{r} = kz\cos\theta + kx\sin\theta$

The photographic plate upon which the reference beam falls is assumed to be at $z = 0$, thus equation (1) becomes

$$\bar{r}(x, y) = A\cos(kx\sin\theta - \omega t)$$

Using $k = \dfrac{2\pi}{\lambda}$ and put $\dfrac{\sin\theta}{\lambda} = \alpha$

$$\therefore \qquad \bar{r}(x, y) = A\cos(2\pi\alpha x - \omega t) \qquad \text{......(2)}$$

If the object is a point scatterer, the spherical object wave is given by

$$\bar{o}(x, y) = \frac{A}{r}\cos(kr - \omega t + \phi)$$

The symbols have their usual meanings. Since the object is made up of large number of points then the wave reflected from the object is the vector sum of all waves reflected from different points of the object. Such an object wave is given by

$$\bar{o}(x, y) = a(x, y)\cos[\phi(x, y) - \omega t] \qquad \text{......(3)}$$

Thus the total field $\bar{E}$ at the photographic plate is given by

$$\bar{E} = \bar{r}(x, y) + \bar{o}(x, y) \qquad \text{......(4)}$$

or

$$\bar{E} = a\cos(\phi - \omega t) + A\cos(2\pi\alpha x - \omega t) \qquad \text{......(5)}$$

The photographic plate responds only to the intensity (I) which is proportional to the time average of the square of the resultant field (E). So we have

$$I(x, y) \alpha \langle E^2(x, y) \rangle$$

or

$$I(x, y) = \langle E^2 \rangle$$

The constant of proportionality is taken to be 1.

$$\therefore \quad I(x, y) = \langle [a\cos(\phi - \omega t) + A\cos(2\pi\alpha x - \omega t)]^2 \rangle$$

$$I(x, y) = \langle a^2\cos^2(\phi - \omega t) \rangle + \langle A^2\cos^2(2\pi\alpha x - \omega t) \rangle + \langle 2aA\cos(\phi - \omega t)\cos(2\pi\alpha x - \omega t) \rangle$$

$$I(x, y) = a^2\langle \cos^2(\phi - \omega t) \rangle + A^2\langle \cos^2(2\pi\alpha x - \omega t) \rangle + 2aA\langle \cos(\phi - \omega t)\cos(2\pi\alpha x - \omega t) \rangle \quad ......(6)$$

Using

$$\langle \cos^2(\phi - \omega t) \rangle = \frac{1}{2} \quad ......(7)$$

$$\langle \cos^2(2\pi\alpha x - \omega t) \rangle = \frac{1}{2} \quad ......(8)$$

and

$$\cos(\phi - \omega t)\cos(2\pi\alpha x - \omega t) = \frac{1}{2}\cos(\phi + 2\pi\alpha x - 2\omega t) + \frac{1}{2}\cos(\phi - 2\pi\alpha x)$$

Here we used the identity

$$\cos A\cos B = \frac{1}{2}\cos(A + B) + \frac{1}{2}\cos(A - B)$$

$$\therefore \quad \langle \cos(\phi - \omega t)\cos(2\pi\alpha x - \omega t) \rangle = \frac{1}{2}\langle \cos(\phi + 2\pi\alpha x - 2\omega t) \rangle + \frac{1}{2}\langle \cos(\phi + 2\pi\alpha x) \rangle = \frac{1}{2}\cos(\phi - 2\pi\alpha x) \quad ......(9)$$

The first term vanishes since the time average of cos is zero.

Putting eqns 7, 8 and 9 in equation 6, we get

$$I(x, y) = \frac{a^2}{2} + \frac{A^2}{2} + aA\cos(\phi - 2\pi\alpha x) \quad ......(10)$$

This is the equation of the intensity pattern recorded in the photographic plate. This equation shows that the phase of the object wave $\phi(x, y)$ is recorded in the intensity pattern. When the photographic plate which has recorded the above (eqn 10) intensity pattern is developed, we obtain a hologram.

For the reconstruction of the image from the hologram, the hologram is illuminated with laser beam called reconstruction wave $R(x, y)$ which is identical to the reference wave $r(x, y)$. Let $T(x, y)$ be transmitted field then $\frac{T(x, y)}{R(x, y)}$ is called the amplitude transmittance. This transmittance depends on $I(x, y)$. By a suitable developing process one can obtain a condition under which the amplitude transmittance is linearly related to $I(x, y)$

i.e.

$$\frac{T(x, y)}{R(x, y)} \alpha I(x, y)$$

Taking the constant of proportionality equal to 1, we have

$$T(x, y) = R(x, y)I(x, y) \quad ......(11)$$

Substituting for $R(x, y)[= r(x, y)]$ and $I(x, y)$ from eqns 2 and 10, we get

$$T(x, y) = A\cos(2\pi\alpha x - \omega t)\left[\frac{a^2}{2} + \frac{A^2}{2} + aA\cos(\phi - 2\pi\alpha x)\right] \quad ......(12)$$

$$T(x, y) = \left(\frac{1}{2}a^2 + \frac{A^2}{2}\right)A\cos(2\pi\alpha x - \omega t) + A^2a\cos(2\pi\alpha x - \omega t)\cos(\phi - 2\pi\alpha x)$$

$$T(x, y) = \left(\frac{1}{2}a^2 + \frac{A^2}{2}\right)A\cos(2\pi\alpha x - \omega t) + \frac{A^2a}{2}[\cos(\phi - \omega t) + \cos(4\pi\alpha x - \omega t - \phi)]$$

$$T(x, y) = \frac{1}{2}\left(\frac{a^2}{2} + \frac{A^2}{2}\right)A\cos(2\pi\alpha x - \omega t) + \frac{A^2a}{2}\cos(\phi - \omega t) + \frac{A^2a}{2}\cos(4\pi\alpha x - \omega t - \phi) \quad ......(13)$$

This gives the transmitted field in the plane $z = 0$

In the equation above there are three terms. First term is nothing but the recon struction wave but the amplitude is modulated. The second term represents the object wave (see eqn 3) apart from a constant $\frac{A^2}{2}$. This gives rise to a virtual image. Thus we can say the effect of viewing this wave is same as viewing the object itself. The last term represents a rotated (due to the presence of $4\pi\alpha x$) object wave with opposite curvature (due to the presence of $-\phi$). So it gives rise to a real image of the object which can be photographed.

Note : It may be noted that the reconstruction wave need not be the same as the original reference beam. If a reconstruction wave of wavelength λ greater than that of original reference beam wavelength we get an enlarged image and vice versa. That is all.

Different types of holograms

(i) Reflection holography

While constructing hologram the object beam and the reference beam reach the recording medium from opposite directions. The beams combine within the medium and generate interference fringes which are recorded in the thick emulsion. During reconstruction the hologram scatters the illuminating back towards the viewer. One sees a virtual image behind the hologram as if looking into a mirror. Hence called reflection holography. This is also called as thick emulsion holography since this technique utilises a thick emulsion on the photographic plate.

(ii) Volume holography

In this method the object wave is reflected from the object and propagates backward and overlaps the incoming reference wave. The two waves form standing wave pattern. The fringes are recorded by the photo emulsion throughout its entire thickness to form a volume hologram. This hologram acts as a 3D grating and obeys Bragg's law ($2d\sin\theta = n\lambda$). Therefore by changing the incident angle or wavelength a number of holograms can be stored in the medium. Different and mutually incoherent laser beams may be used to produce different components of holograms of the object and when they are illuminated a multicoloured image is seen.

(iii) White light reflection holography

Here the hologram is generated using coherent light but in the reconstruction process an ordinary white light beam having a wavefront similar to the original waves is used. Using coherent sources at different wavelengths several holograms are stored in a single film. When the hologram is illuminated by ordinary white light, a multicoloured image is seen in the reflection.

(iv) Rainbow holography

Here a rainbow hologram is constructed. The construction of this hologram is cumbersome. This allows more convenient illumination by white light rather than by lasers. When the hologram is viewed with a white light a very bright coloured image can be reconstructed. Rainbow holograms are commonly seen today on credit cards as a security feature and on product packaging.

Applications of hologram

Ever since in its commercial usage in the 1970's there is no looking back for holography and hologram products. The demand has only manifolded with each passing year. Holography has found its applications in almost all industrial sectors including commercial and residential applications.

Areas of holographic applications

Holography can be used for a broad range of applications. We give below a detailed explanation of some of the popular areas in which holograms are used.

(i) Holographic interferometry

This is a very important holographic technique for studying the distortions in objects resulting from stresses, strains, heat and vibrations etc. In this the original object and the object after deformation are recorded on the same hologram. When the hologram is illuminated with the reference wave, both the images are viewed simultaneously. Since the waves are slightly different the two images form interference fringe pattern indicative of the changes suffered by the object.

(ii) Security hologram

One of the fastest and the most popular growing area for the use of holograms i the security and product authentication. The presence of holograms indicates th authenticity of these items. They provide a powerful obstacle to counterfeiting. Th security holograms have proven to be unsurpassed when added to documen anticounterfeiting. Nowadays we can see holograms on credit cares, phone car drivers licences etc.

(iii) Display holography

Display holography use all types of holograms from decorative foils to disp holograms to eye catching stereograms. It is used in corporate display, trade s etc.

(iv) Holography in entertainment

Holograms are used in the entertainment industry extensively. Various H wood movies specially the science fiction films have used holographic spec fects. Even movie posters are made holographic. Holograms are also used as promotional tools on records and CD covers.

(v) Holography in packaging

This is one area where holograms have become popular. The holographic packaging provides eye catching visual impact, authentication and added value. In reality all products are subject to counterfeiting, hence proper holographic packaging on consumer goods serve an important way for brand protection.

(vi) Holography in medical field

Holographic technique is also used in various medical applications like CAT scans, X-rays, MRI, ultra sound, ophthalmology, endoscopy and many more.

(vii) Holographic optical instruments

Holographic lenses and diffraction grating are optical devices in which the object is a mirror or a lens. Both are diffractive devices but functions like mirrors or lenses. They can be used to perform more specialised functions like making the panel instruments of a car visible in the windshield for increased safety. They are also used in barcode scanners, office copy machines, solar concentrators etc.

UNIVERSITY MODEL QUESTIONS

Section A

(*Answer questions in* **two** *or* **three** *sentences*)

Short answer type questions

1. What is photography?
2. What is meant by holography?
3. Distinguish between photography and holography.
4. What are the principles used in holography?
5. What is a hologram?
6. What are the important properties of hologram?
7. What are the advantages of a hologram over an ordinary photograph?
8. What is the peculiarity of a rain bow hologram? What is its use?
9. Give two applications of holography.
10. What is the principle of construction of hologram?

Section B

(*Answer questions in a* **paragraph** *of about half a page to one page*)

Paragraph / Problem type questions

1. Briefly explain the principle of hologram.
2. Briefly explain how hologram is constructed
3. Explain how image is constructed from a hologram.
4. Briefly explain reflection holography.
5. Explain volume holography briefly.
6. Explain white light reflection holography.
7. Explain rainbow holography.
8. What is holographic interferometry?
9. Explain briefly how does hologram use as a security device.
10. What is meant by holographic optical instrument?

Section C

(*Answer question in about* **one** *or* **two** *pages*)

Long answer type question (Essay)

1. Explain the theory of construction of a hologram and reconstruction of image from a hologram in detail.